PHOTON WELDING DEVICES FOR JOINING PLASTIC PARTS

CROSS REFERENCE TO RELATED APPLICATION(S)

This application claims priority of U.S. Provisional Patent Application No.

5   60/260,012 entitled "PHOTON WELDING DEVICES FOR JOINING PLASTIC PARTS,"
filed on January 6, 2001, the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for welding plastic parts, and more
10   specifically, for devices to weld plastic parts using Through Transmissive Infrared
Radiation (TTIR).

Typically, plastic assemblies can be welded together by one of the many
methods for welding or joining plastics currently available. These methods include
ultrasonic welding, adhesives, fasteners, friction, hot plates, induced welding,
15   microwave welding, or radiant heaters. Although these methods sometimes produce
welds of adequate strength, often they are not adequate and each has some
drawbacks. For example, vibration during frictional welding can damage installed
electronic devices or the plastic pieces. Furthermore, part size and positioning accuracy
are limited because one part must move relative to the other during the procedure. Melt
20   residue deposited on hot-plate tooling requires frequent cleaning. On the other hand,
the relative high temperatures required for non-contact, radiant heaters could degrade
materials at the weld joints or overheat sensitive electronics.

Other methods used to weld plastics include the use of coherent light sources
like lasers (Nakamata), or non-coherent light sources like halogen lamps (Grimm et al).

25   Nakamata (U.S. Patent No. 4,636,609 "Process for joining different kinds of
synthetic resins.") shows a TTIR method of joining different plastics by using a substrate
plastic doped with an absorbing element (e.g. carbon) to decrease the transmissivity of
the plastic and thus absorb the energy produced by the radiant source. The energy
absorbed by the substrate plastic generates enough heat to bring the component to its
30   melting point. Because the substrate plastic is in intimate contact with another piece of

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the same material (but without an absorbing element), when the substrate melts, so does the other component (this component is typically transparent). Radiant energy from the monochromatic source (a laser) is directed through the transparent plastic to the substrate plastic. Heating in the substrate plastic is transferred to the transparent

5   plastic by conduction in the area where both components meet. When both the substrate and the transparent component are melted, the two pieces are pressed together, the source of radiation is terminated, and then the assembly is allowed to cool producing a satisfactory weld.

A laser is the only radiant source specified in this patent. A neodymium-doped

10 YAG (Yttrium Aluminum Garnet) laser with a radiant output at a wavelength of 1060 nm (nanometers) is the most suitable according to the inventor. A neodymium-doped glass laser, a ruby laser, a helium-neon gas laser, a krypton gas laser, an argon gas laser, a hydrogen gas laser, or a nitrogen gas laser may also be used. Nakamata contends that laser radiation sources with a wavelength of 1060 nm (the neodymium-doped YAG

15 wavelength) or less is necessary. Wavelengths longer than the aforementioned 1060 nm cannot be transmitted through the otherwise transparent plastic according to the inventor.

Nakamata teaches that 5 to 100 watts of laser power are necessary to affect satisfactory welds. No melting occurs at power levels less than 5 watts, and laser power

20 levels in excess of 100 watts may vaporize or significantly alter the properties of the transparent plastic.

Grimm is the inventor of two related TTIR method patents (U.S. Patents No. 5,840,147 and 5,843,265) assigned to the Edison Welding Institute and licensed to Quantum Group Inc. Grimm utilizes a similar scheme as Nakamata to bond two plastic

25 pieces. That is, a base layer of plastic is absorbing and is heated by incident radiation. A second plastic piece, which is to be bonded to the base layer, is essentially transparent to the radiation employed and is placed on top of the base layer. Incoming radiation, as in Nakamata, is routed through the almost transparent top piece and into the absorbing base layer. Bonding occurs when the base piece melts at the interface with the top piece. Pressure is applied to press the two parts together, the radiation is

30 with the top piece. Pressure is applied to press the two parts together, the radiation is

terminated, and the assembly is allowed to cool. Grimm's bonding method is similar to Nakamata's except for the radiation source. Nakamata employs a laser, and Grimm uses a source of non-coherent electromagnetic radiation.

Grimm utilized a source of, non-coherent electromagnetic radiation, a quartz-halogen-tungsten lamp, which can be described as an approximately gray body emitter. Grimm cites a problem with his radiation source, his source is a broadband emitter that generates substantial amounts of long wavelength IR (Infrared) that are absorbed in his supposedly transparent plastic piece. This causes the same problem that Nakamata experienced in his transparent plastic with high power lasers (power levels greater than 100 watts). Grimm employs the inventive step of utilizing an extra piece of transparent plastic placed between his source and the work piece to absorb the long wavelength energy. Grimm devises a method of cooling (forced convection) this extra piece of plastic to dissipate the heat generated in this kind of filtering technique.

The technique of Nakamata and Grimm may be employed for critical bonding applications providing the thermal energy delivered by the welding process can be limited. A very narrow bond line is a practical method of achieving hermeticity at limited power levels. Nakamata's sealing method can provide a narrow bond line because of the non-diverging nature of a laser beam (i.e. a laser with a wavelength of 808 ± 10 nm has a 0.8 mm beam diameter). Grimm, however, provides a wider beam by using a lamp and reflector system with the weld at the focal length of the lamp/reflector system. In both of these approaches, either the optical source or the work piece (or both) must move in the appropriate trajectory to accomplish the bond at the required location. The correct amount of compression force for the requisite amount of time must follow the beam, and this requires complicated, automated tooling or robotic systems. In this approach, furthermore, there is an inherent discontinuity at the starting point and at the ending point of the weld, which may effect the quality of the product. Goldstein and Tolley disclosed a TTIR method using a photon reflecting mask in U.S. Patent Application Number 60/116/575 Filed January 21, 1999 and 09/488,887 Filed January 21, 2000.

SUMMARY OF THE INVENTION

This photon welding apparatus, which is capable of producing a narrow or controlled bond line, is used to bond a transparent or translucent plastic top layer to a base piece molded of a plastic that contains carbon or similar material to absorb

5 incident photon energy. In an example the base piece consists of a cavity that may contain sensitive chemicals, membranes, or other vulnerable components. The base geometry is not limited to a circular structure; this photon welder readily processes square, rectangular, polygonal or other geometrical shapes. It is convenient that the vertical wall of the cavity contain an interior shoulder or ledge on which the transparent

10 or translucent top or cap rests. The cap may be molded, or it may be blanked out of plastic sheet. If the internal ledge for positioning the cap is not feasible, external fixturing to keep the two parts of the assembly in registration may be employed.

Photon energy (produced by a non-coherent light source) is introduced in a very specific pattern around the periphery of the package along with a compressive force

15 exerted by a light pipe or a thin mask. The light pipe is made of fused silica (silicon dioxide) or other suitable material, and may be round, square or any other geometry. The end of these light pipes is machined so that a thin raised section of quartz conforms to the weld location desired and can be as little as a fraction of a millimeter wide, at the package's periphery. The width of the thin raised section is governed by the width of the

20 weld bond desired. The raised section of the light pipe, about 1 mm high, is in contact with the cap during the weld cycle and transmits photon energy from the light pipe into the transparent or translucent layer. All surfaces at the end of the light pipe that are not in contact with the work piece are coated with a metallic (gold, silver, aluminum, chrome, etc.) reflecting layer. This reflecting layer returns photons not participating in

25 the weld back to the optical source. Therefore, in this process photon energy is delivered in a precise pattern by this optical mask to the work piece to generate the desired narrow controlled bond line.

A convenient photon source is a quartz halogen tungsten lamp which is optically coupled to the free end (machined flat and fire polished) of the light pipe with the aid of

30 an elliptical, parabolic, or other suitable reflector structure. These lamps exhibit spectra

that peak in the infrared at about 1000 nm for filament temperatures about 3000 K and can be used to produce quality welds in the apparatus described. Lamp life may be prolonged by operating the lamp at reduced power and still obtain satisfactory welds.

In addition to photon energy, a compressive force must be applied to the two components being bonded. This compressive force is applied during the bonding step and for a short period measured in seconds after the photon radiation ceases. One of several methods that can be utilized to apply a compressive force consists of placing the components to be bonded into spring loaded nests. The components are then brought into direct contact with the free end of the light pipe structure. As the springs are compressed, the force required for a proper weld is then applied on the components and precisely only on the areas to be welded. Data collected through a lot of experimentation indicates that forces of about 45 N (Newtons) are needed for components within 25 to 30 mm in overall width or diameter. The light pipe and photon source may move and apply the compression force to the work piece. Alternatively, the work piece may move and be compressed against the masked end of the light pipe with a calibrated force. Air cylinders, solenoids, springs, cams or similar mechanical actuators may provide the controlled force.

A number of system parameters must be controlled for satisfactory bonds, these parameters include exposure time, initial component temperature, compressive force applied, temperature of the light pipe, and level of irradiance applied. For example, the compression force applied to a work piece of about 25 mm diameter and a thickness of 1 mm during and after the bonding process must be maintained at 45 N. The same part requires photon exposure times of 10 seconds and a post-weld compressive force to be maintained for an extra 5 seconds to allow stress relief of the bond. Experiments have shown that if the same components are pre-heated to 110 °C, than the exposure time for bonding can be reduced to about 5 seconds with a post-weld force to be maintained for only 3 seconds. The temperature of the light pipe and mask is another parameter that must be controlled. Testing in this area suggest that the light pipe's temperature affects the quality of the weld as well as the component in contact with it. These same tests indicate that light pipes are to be maintained at temperatures no greater than 70

°C at the beginning of the weld cycle. To control the light pipe's temperature, after a weld, a cooling gas, circulating liquid, forced convection, or related cooling means may be employed to lower the light pipe temperature to an acceptable level in a timely manner. Levels of irradiance of about 15 to 20 W/cm^2 (for a wavelength range between 400 to 1100 nm) are required to bond components such as the ones described above. Comparisons performed between components bonded with different systems including ultrasonic and laser indicate that photonic welds are stronger, cleaner, and more consistent than welds performed with other methods. Yields of 99% were easily achieved with photonic welding systems. Ultrasonic methods yielded results as low as 70% with overall questionable weld consistency and low strength at the bond line. Laser welds were performed using a bundle of optical fibers conformed in the shape of the welding area of the components. A sample of these components were welded and then tested in house and results indicated that 14 to 28% of the components were improperly welded or had very weak bond lines. In general, however, the simplicity of the photon welding system is superior overall to the other systems tested even though some of them were faster. The data in the description below show the advantages of the TTIR photon welding system.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of this invention will become more apparent from the following taken in conjunction with the accompanying drawings, and in which:

FIGS.1a and 1b are cross-sectional views showing an apparatus designed with the principles described in the present invention;

FIGS. 2a and 2b are cross-sectional views showing a second apparatus designed with the principles described in the present invention;

FIG. 3 is a cross-sectional view showing a radiant source bonding two components of the work piece in accordance to the basic embodiment of the process according to the present invention;

FIGS. 4a and 4b are cross-sectional views of two light pipes designed to conform to the principles established in the present invention;

FIGS. 5a through 5d are cross-sectional views showing various cooling schemes for the light pipes;

FIGS. 6a and 6b are cross-sectional views showing a third apparatus designed with the principles described in the present invention;

5   FIGS. 7a through 7h are cross-sectional views showing a step-by-step welding process of a fourth apparatus designed with the principles described in the present invention;

FIG. 8 is a top view of a fully automated conveyor system where plastic components are processed continuously under an apparatus similar to those described

10   on figures 1, 2, 6, and 7;

FIG. 9 is a cross-sectional view of a welding apparatus used on a system such as the one described in Figure 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

15   Figure 1a shows an embodiment of a photon welder, which comprises several features of the current invention. A component made with highly absorptive radiation characteristics 110, is placed in intimate contact with another component that allows transmission of radiant energy 109, into a nest or base 114 with means to provide a force 111, which could be provided by springs 117, or a linear actuator or other device

20   that will produce the same result. A movable plate 115 provided with bushings 116 is pushed upward by a pneumatic piston 119 as Figure 1b shows. The plate carries the nest 114 upward in a linear motion and maintains alignment to a light pipe or a thin mask composed of a transparent material such as silicon dioxide and a reflective material placed on all locations except where the welding of the components is desired.

25   The plate moves along shafts 124 to aid on the alignment of the components to be welded and the light pipe or thin mask. When in contact with the shaped and masked end of the light pipe 105, the movable plate 115 activates a contact switch or a proximity sensor (not shown) which turns on the light source 101. The elliptical reflector 102, directs light produced by the source towards the light pipe 105. A fan 112 provides

30   cooling 113 to the reflector 102 continuously. Radiation 104, impinging on the entrance

of the light pipe 105, travels through the pipe 106, through the exit of it, and then through the first component 109 that comprises part of the assembly to be bonded. Finally, the radiation is absorbed by the second component 110 of the assembly causing it to melt and transfer energy upward to the top component by convection and

5   conduction, which melts a portion of the top component. The melted area cools to a bond during a dwell time of 1 to 4 seconds. Upon completion of the weld, a timed controller (not shown), retracts the movable plate 115 to its original position as shown on Figure 1a. To prevent over-welding or the melting of plastic components (distorting the exterior surfaces), the temperature of the light pipe is controlled by a temperature

10   sensor 130, which activates a fan or blower 118 providing cooling air to the exit end of the light pipe.

Figure 2a shows another embodiment of a welding device designed with the principles established by the invention. On this version, the linear motion is provided to the light pipe 205, the light source 201, reflector 202, and the fan 212, by a piston 219

15   located on a retaining plate 222 provided with bearings 216. A movable plate 223 also provided with bearings 216 slides downwards on shafts 224 simultaneously with the retaining plate 222 and movable plate 223. When the plates slide downward (Figure 2b), the light pipe 205 with its shaped and masked end comes in contact with the components to be bonded 209 and 210. As the plates move downward, a contact switch

20   or a proximity sensor (not shown) activate the light source 201. Light produced by the source 201 is directed by the elliptical reflector 202, towards the light pipe 205. A fan 212 provides cooling 213 to the reflector 202 continuously. Radiation 204 impinging on the entrance of the light pipe 205 travels through the pipe, the exit of it, and then through the first component 209 that comprises the assembly to be bonded. Finally the

25   radiation is absorbed by the second component 210 of the assembly causing it to melt and thus bond with the first component of the assembly. Upon completion of the weld, a timed controller (not shown), retracts the movable plate assembly (222 / 223), to its original position as shown on Figure 2a. To prevent over-welding or the melting of plastic components, the temperature of the light pipe is controlled by a temperature

sensor 230, which activates a fan or blower 218 providing cooling air to the exit end of the light pipe.

Figure 3 illustrates a third embodiment of the invention. A quartz-halogen tungsten lamp 301 (typically 410 to 1000 watts in machines, although not limited to these powers) includes an elliptical reflector 302 coated with highly reflective material 303 (aluminum or gold coated onto elliptical metal reflector). Photons 304 reflected by the walls of the metal reflector is directed towards the entrance of a light pipe 305 made of fused silica (quartz). Photons 304 produced by the light source 301 travel the length of the entire light pipe 306. An exit is provided for the photons 304 at predetermined areas at the end of the light pipe 305. A highly reflective material 308, acting as a mask, placed at the end of the light pipe prevents photons from exiting through unwanted areas.

With the top plastic component 309 in intimate contact with the bottom plastic component (e.g. in the form of an L-shaped recess 310a or a butt joint 310b) and held clamped between the light pipe and a base (not shown) a force is applied 311, the light source 301 is energized, photons 304, reflected by the reflector's surface 303, are transmitted by the light pipe 305 and through the material of the top component 309, and finally absorbed by the material of the bottom component 310. Because both the top plastic component 309 and the bottom plastic component 310 are in intimate thermal contact, when the bottom photon absorbing plastic component 310 melts, the top transparent plastic component 309 melts too as the heat is transmitted to it by conduction and convection.

Figures 4a and 4b depict two basic light pipe configurations where a point of entry is provided for the light 427, a path for the light is provided 405, and a masked area 408 to prevent radiation from striking unwanted sections is placed at the point of exit of the light pipe. The masked area of the light pipe is coated with a highly reflective material such as gold or aluminum. The weld location is determined by a small area on the periphery of the quartz light pipe, which is not coated with reflective material 428.

Figures 5a through 5d describe several embodiments of this invention, which provide thermal management to the end of the light pipe because the light pipe absorbs

heat during each weld. These embodiments include (Figure 5a) the use of heat dissipaters or heat sinks 531 provided with radial fins 532; Figure 5b shows a water cooled heat exchanger 533, wrapped around the light pipe with water 534, forced through it to maintain the temperature of the light pipe at appropriate levels; heat pipes

5   (Figure 5c) can be utilized 535 along with a fan 537 to help remove the heat from the light pipe 536, thus cooling the light pipe; and Figure 5d shows an annulus 538, where compressed air is channeled through openings to cool the light pipe 539.

Figures 6a and 6b depict a manual welding device based on the principles established by the invention. A component made with high absorptive radiation

10   characteristics 610, is placed in intimate contact with another component that allows transmission of radiant energy 609 into a nest or base 614 with means to provide a force 611 with springs 617 or other device that will produce the same result. A movable plate 615, provided with bushings 616, is pushed upwards by a cam 641 mounted on a shaft 640 turned manually. As Figure 6b shows, the plate carries along a nest 614

15   upward in a linear motion and maintains alignment to the light pipe by shafts 624. When in contact with the shaped and masked end of the light pipe 605, the movable plate 615, activates a contact switch or a proximity sensor (not shown) which turns on the light source 601. Light produced by the source is directed by the elliptical reflector 602, towards the light pipe 605. A fan 612, provides cooling 613 to the reflector 602

20   continuously. Radiation 604, impinging on the entrance of the light pipe 605, travels 606 through the pipe, the exit of it, and then through the first component 609 that comprises the assembly to be bonded. Finally the radiation is absorbed by the second component 610 of the assembly causing it to melt and thus bond with the first component of the assembly. Upon completion of the weld, the operator moves the crank (not shown) in

25   the opposite direction and allows the movable plate 615, to retract to its original position as shown in Figure 6a. In order to prevent over-welding or the melting of the plastic components, a temperature sensor 630 initiates cooling. A small fan 618 provides cooling air to the exit end of the light pipe.

Figures 7a through 7h present another welding apparatus where the light pipe
705 remains in a fixed position, while a linear actuator 745, provides a linear motion to a
nest 714, held in a drawer-like fixture 742. The figures depict the step-by-step process
required to complete the welding of two components in this embodiment. Figure 7a

5   presents the device in its initial position right after power has been turned on. Both the
reflector's cooling fan 712, and the light pipe cooling mechanism 718 are on at this
point. Sensors (not shown) provide feedback to the system to activate a pneumatic
piston 743 to move a drawer mechanism 742, out and away from the welding area. The
drawer mechanism holds a nest 714. The nest holds the components to be welded 709

10   and 710. Upon loading the nest with a work piece assembly (Figure 7b) containing both
a transparent part 709 and an absorptive part 710, the operator pushes a momentary
switch 744, to initiate the welding process. When a sensor (not shown) ascertains that
the work piece is in the correct position, the pneumatic piston 743 returns the drawer
742 back to its position within the welding area. A linear actuator 745, or a similar

15   device that provides the same motion lifts a holding nest 714, to the welding position.
This action is sensed by yet another sensor (not shown) which stops the cooling
mechanism to the light pipe 718. In this position, the linear actuator 745 provides the
required clamping force. As the shaped and masked end of the light pipe contacts the
plastic assembly consisting of a transparent component 709, and a dark component 710

20   a proximity sensor or a mechanical switch (not shown) triggers the radiant source 701
on. A timer (not shown) provides the mean to control the time the plastic components
are to be irradiated. A fan 712, provides continuos cooling 713 to the reflector 702. A
temperature probe 730 attached to a temperature control (not shown) provides
feedback to a programmable device (not shown). When the welding is complete, the

25   linear actuator lowers the components (Figure 7f), which triggers the light pipe cooling
mechanism 718 on. A pneumatic piston 743 moves the drawer-like mechanism 742 out
and away from the welding area. The operator removes the welded plastic components
751 from the holding nest 714, and inserts a new pair of components to be welded. The
cycle is repeated when the operator pushes the momentary switch 744.

Because of their simple nature, welding machines designed using the principles established in the invention are ideal for fully automated systems. An electronic control box provided with a touch panel (not shown), allows full programming of the step-wise welding process presented on Figure 8. A conveyor belt-driven system 800 in

5 combination with miniature pneumatic pistons and sensors is utilized to move the components to be welded. Unwelded plastic components are assembled and then placed on holding nests 801. The conveyor moves the nests under a pre-heating system 802 for some pre-determined time, then under a photonic welder 803, were bonding is performed. Bonded components exit the welder and then complete the cycle

10 by returning to the point of origin for loading and unloading of the components.

A sequence control system using PLC programming provides the controls for moving a palette containing the plastic parts to be welded, positioning the parts in a pre-heat station, and then positioning the parts in the welding station. At each station, welding parameters (including time duration, light intensity, retaining force) are set and

15 error messages indicate if any of the welding parameters are out of tolerance.

At the pre-heating station the plastic part temperatures are increased by about 50 °C. This preheat has been determined for reservoir components made of polyethylene in both square and circular geometry's of 25 to 30 mm (per square side or diameter). Data obtained on preheat showed the following: small preheat produces excellent

20 quality welds, but only a small reduction in weld time; a proper preheat (typically about 50 °C) results in the time reduction to weld the 3 mm thick infrared transparent polyethylene parts from nine to six seconds; and excessive preheat results in overwelded parts with visible distortion of the normally undisturbed exterior surface. If the preheat varies outside of the specified range (plus or minus 10 °C) around a

25 predetermined temperature (which is adjustable depending on the plastic part geometry and material) then an error message will signal the system to stop.

After preheat, the conveyor transports the palette and plastic parts to the welding station. At this welding station, the plastic parts are lifted to position the parts under the welding lens. Three different welding lenses have been tested. These are: a thin

30 laminated glass lens with an embedded gold, silver or aluminum mask; a machined

quartz lens with aluminum coating mask; and light pipes up to two inches in diameter with masks at the end to allow light only in the weld region. Data obtained on weld force has determined that 7 to 10 pounds provide highest quality welds for polyethylene. Lower forces result in incomplete welds around the periphery, and higher forces distort

5   the normally clean exterior surface. Both the force magnitude, and duration of force are controlled. The part is raised by a pneumatic system to the lens were the predetermined force is applied. After the force is applied, then the welding lights are activated and the welding is commenced for a predetermined time. The PLC program controls both the force and the welding times, and if these are out of range then an error message

10 detects the deviation. After the welding light is turned off the force application continues for one second and cooling air is applied to the welding lens for three seconds. The software allows different sequencing times depending on the plastic part geometry and materials.

Figure 9 shows a photon welder were a belt driven mechanism 901 such as the

15 one described on Figure 8, moves a nest 902 carrying unwelded components 903. Air driven pistons 904, push the unwelded components against a short light pipe 905. A moment later, quartz halogen lamps 906 contained within elliptical reflectors 907 are turned on for some pre-determined time controlled by a fully programmable control station (not shown). The light is then trapped by long cylindrical light pipes 908 which

20 direct the light towards short light pipes that have been masked with aluminum or gold to conform the areas of the parts to be welded 905. While the bonding takes place, a continuous stream of air cools both ends of the light pipes. The stream of air is provided by jets 909. Cooling for the reflectors and the chamber 911 where the light pipes and reflectors are contained is provided by various fans 910. Upon completion of the weld,

25 the pneumatic pistons retract allowing the welded components to be carried away by the nest 902.

Those skilled in the art realize that many other modifications may be made without departing from the spirit of this invention.